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Shift Work, Age, and Performance: Investigation of the 2-2-1 Shift Schedule Used in Air Traffic Control Facilities
I. The Sleep/Wake Cycle

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16. Abstract

Air Traffic Control Specialists (ATCS) work rotating shift schedules for most of their careers. Specifically, many work a counterclockwise rotating shift schedule, called the 2-2-1, or some variation of the schedule. The 2-2-1 involves rotating from two afternoon shifts to two mornings and, finally, to a midnight shift over the course of one work week. The purpose of the present study was to investigate sleep patterns during this type of rotating shift and the potential cumulative partial sleep loss in a laboratory-based synthetic work environment. METHODS. Four groups of five male subjects between the ages of 30 to 35 (n-10) and 50 to 55 (n=10) participated in the four week study. Subjects were screened on medical and cognitive criteria. The Multiple Task Performance Battery (MTPB) was utilized to provide a motivating synthetic work environment. Subjects were asked to work three 2-hour sessions on the MTPB per eight hour day for the last three weeks of the protocol. During the second and fourth weeks, subjects worked day shift (0800-1630). During the third week, subjects worked the 2-2-1 schedule. Sleep duration and quality, as well as mood, sleepiness and fatigue ratings were reported in log books. Wrist activity monitors were used to verify sleep duration. RESULTS. Average sleep durations decreased over the week of the 2-2-1 from an average of 7.6 hours, on Sunday night prior to the first afternoon shift, to 3.0 hours just prior to the midnight shift. Comparison of sleep duration for the first week of day shifts (excluding weekends) to the 2-2-1 week revealed that total sleep time was significantly less for the 2-2-1 week ($p<.01$). No differences were found between age groups. DISCUSSION. Data suggest that sleep management interventions could improve adaptation to the quick-rotating shift schedules. This study was the first report from a laboratory-based study of the 2-2-1. It was part of a research program designed to develop fatigue countermeasures for implementation with Air Traffic Control Specialists in the field.

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SHIFT WORK, AGE, AND PERFORMANCE: INVESTIGATION OF THE 2-2-1 SHIFT SCHEDULE USED IN AIR TRAFFIC CONTROL FACILITIES I. THE SLEEP/WAKE CYCLE

INTRODUCTION

Because Air Traffic Control (ATC) operations require 24-hour per day staffing, Air Traffic Control Specialists (ATCS), in many cases, are faced with shift work throughout their careers. ATCSs in the United States work a relatively unique rapidly rotating shift schedule, the "2-2-1" (Price & Holley, 1990), as well as a variety of schedule modifications based upon a backward or counterclockwise rotation of shifts. Problems associated with shift work in other populations could be expected to be found in the ATCS population. These include issues related to health, family, life styles, sleep patterns, performance on the night shift, and stress (Moore-Ede, Czeisler, & Richardson, 1983; U.S. Congress, Office of Technology Assessment [OTA], 1991). The sources of stress include sleep deprivation, circadian rhythm disruption, and disruption of social interactions (Scott & LaDou, 1990). Each of these factors has implications for job performance. Because of the safety-related nature of the ATCS's job, assessing and understanding the factors that potentially affect job performance, and the manner in which they interact and change with age, is critical.

The 2-2-1 schedule was the focus of this research. The 2-2-1 requires ATCSs to work two afternoon shifts, followed by two morning shifts, and finally a night shift, within a five-day period. The rapid, counterclockwise rotations require that employees arrive at work progressively earlier throughout the schedule, thereby compressing the work week. In this schedule, a 40-hour work week is completed within 88 hours, as opposed to the 112 hours required on a straight-day schedule, and it results in 80 hours off between work weeks, compared to 62 hours on straight days. The transitions from the afternoons to mornings and from the mornings to the night shift involve "quick-turnarounds," with as few as eight hours off between shifts.

The 2-2-1 schedule raises a number of specific issues about shift design, and arguments can be developed both in support of and against the schedule, in the context of chronobiological principles. Certain researchers in shift work design would not recommend the counterclockwise rotation because of the potential for sleep loss, circadian rhythm disruption, and possible resultant feelings of fatigue or performance decrements. On the other hand, the schedule minimizes employee exposure to the night shift, and has been used successfully in ATC facilities for several decades. There is little evidence, however, to support either position (Turek, 1986).

This laboratory-based study was designed to investigate empirically the extent to which the 2-2-1 schedule resulted, or failed to result, in sleep and circadian rhythm disruption, performance decrements, and changes in subjective measures of sleepiness and mood. Because age has frequently been found to relate to performance in ATC (Collins, Boone, & VanDeventer, 1981) and to be a factor in the amount of sleep obtained by night shift workers (Tepas, Duchon, & Gersten, 1993), the study included age as a factor in the investigation.

The results of the study will be presented in a series of reports covering the following areas: the sleep/wake cycle, performance, physiological measures, and subjective measures. This technical report, being the first of the series will present: 1) an overview of the issues associated with shift work with particular focus on the sleep/wake cycle, 2) the study methodology, and 3) the findings related to the sleep/wake cycle.

Overview

ATCSs are responsible for ensuring the separation of aircraft and expediting the flow of air traffic through the National Airspace System (Federal Aviation Administration [FAA] Order 7110.65H). The ATCS's job, particularly in the terminal and en route career options, requires complex cognitive performance which includes activities such as monitoring complex traffic patterns to ensure aircraft separation through application of established rules and procedures, resolution of potential aircraft conflicts, traffic sequencing, assessing developing weather patterns, and providing appropriate adjustments to routing. In 1987, Computer Technology Associates, Inc. (CTA) completed a job task analysis that identified 14 cognitive/sensory attributes required for performing the tasks of extreme or high criticality associated with performance of computer and radar workstation jobs in the current ATC system (Ammerman, Bergen, Davies, Hostetler, Inman, & Jones, 1987). These included coding, movement detection, spatial scanning, filtering, image/pattern recognition, decoding, visualization, short-term memory, long-term memory, deductive reasoning, inductive reasoning, mathematical/probabilistic reasoning, prioritizing, and verbal filtering. Many of these cognitive abilities have demonstrated circadian variations and susceptibility to circadian disruption (Monk, 1990). Therefore, an ATCS's performance of tasks requiring each of these specific skills and abilities could be expected to 1) demonstrate circadian variability and 2) be susceptible to the disruptive effects of shift work on circadian rhythms.

The following excerpt from a report to the Aviation Safety Reporting System (ASRS), a voluntary reporting system operated by the National Aeronautics and Space Administration (NASA), provides evidence that some ATCSs perceive shift work to be a contributing source of problems. In this situation, the reporting ATCS had been involved in an operational error. An operational error occurs when an ATCS allows an aircraft to get too close to another aircraft, a controlled airspace, or the ground. The controller listed three factors contributing to the incident, including shift work-related problems. Specifically noted in the following account was the schedule that is the focus of the present investigation, the 2-2-1:

> Our facility went to a '2-2-1' schedule this year in which we work a combination of evening, day and midnight shifts in each week. Many of the controllers wanted this schedule, but many of us did not. Unfortunately, those of us who did not want it have had it imposed upon us anyway. This is a very specialized schedule designed for resilient people who function normally on 5 or 6 hours of sleep. I am not one of these people. Because my work hours change on a daily basis, I have become unable to form any normal sleep patterns and suffer from bouts of fatigue and insomnia. I know it affects the quality of my performance and I know I am only one of many.

A number of similar reports can be found in the ASRS. These reports, as well as anecdotal evidence from various ATCSs, suggest that shift work, and in particular the 2-2-1, may cause perceived excessive fatigue, sleep loss, and stress, impacts performance, and contributes to operational errors.

Two opposing lines of reasoning can be proposed with regard to the 2-2-1 schedule. Table 1 presents a sample 2-2-1 schedule for reference as the arguments are developed (Melton & Bartanowicz, 1986).

Table 1

The 2-2-1 Shift Schedule

Day	2-2-1	Hours Between
1	1600-2400	14
2	1400-2200	10
3	0800-1600	14
4	0600-1400	10
5	0000-0800	—

The case in favor of the 2-2-1 was made in the literature by Melton and Bartanowicz (1986). They suggested that one advantage of the schedule was that four of the five shifts were worked during normal waking hours. Therefore, employees could maintain relatively stable sleep/wake cycles for the four days of the schedule in order to remain day-adapted. In addition, there was only one shift, the night shift, that was disruptive to the circadian rhythms. It was argued, then, that the 2-2-1 may be less disruptive than other

schedules that require weekly shift rotations in which an employee works one shift for several days, and then rotates to a new schedule, such as "straight-five" shifts, a rotating schedule in which employees work five days on the same shift, have two days off between work weeks, and then rotate to a different shift for five straight work days. Melton and Bartanowicz specifically suggested that the 2-2-1 was better than straight-five shifts. Straight-five shift schedules can result in relatively continuous circadian disruption because during each five-day work week, the body's circadian rhythms may not entrain to one shift until about the time the employee rotates to a different shift. Field studies comparing the 2-2-1 to rotating straight-five shifts found the 2-2-1 to be less stressful (Melton, 1982, 1985). More recent evidence suggests that even employees permanently working straight night shifts do not completely adapt to the schedule (Naitoh, Kelly, & Englund, 1990).

Another advantage of the 2-2-1 schedule may be that it includes only one night shift per week. This minimizes employees' exposure to the problems associated with working the night shift, in addition to minimizing the circadian disruption. The placement of the 2-2-1's single night shift at the end of the week, precludes any circadian disruption due to the night shift from adversely affecting work on the following day.

Certain characteristics of the 2-2-1 schedule, however, are in contrast to current research recommendations about shift design. Examination of the 2-2-1 schedule reveals that it is a continuously counter-clockwise, rapidly rotating schedule, involving two phase-advances of work start times of six hours, each. The quick-turn-arounds provide employees with as little as 8 hours between shifts in which to get home from work, sleep, and return to work. This arrangement has the potential to result in cumulative partial sleep loss during the week because of the two quick-turn-arounds, as well as circadian rhythm disruption. During the transition from the morning shift to the night shift, employees' sleep is additionally compromised by forcing a sleep period during the afternoon. Sleeping in the afternoon is likely to result in poor quality sleep for a variety of reasons, including the daylight in the environment, social and family activities, and circadian rhythms being in a phase that is tending toward increasing rather than decreasing alertness. Depending upon the sleep/wake schedule maintained by the employee, the two quick-turn-arounds could be equivalent to two phase advances in their sleep schedule. In an extreme case, in which an employee failed to maintain sleep/wake patterns conducive to a day-adaptation, sleep patterns could be analogous to flying two west to east jet flights across six time zones and could be predicted to result in symptoms of jet-lag or shift-lag. Placement of the night shift at the end of the week, following the phase advances and possible induction of shift-lag symptoms earlier in the week could cause adverse additive interactions of problems associated with the night shift and shift-lag effects.

Results from the series of CAMI ATC facility field studies on the 2-2-1 schedule indicated sleep loss of approximately 30 minutes per week on the average in 2-2-1 shift workers, as compared to straight-five shift workers. In addition, the results indicated that ATCSs working the 2-2-1 schedule reported more fatigue than those working non-rotating, steady schedules (Melton, 1985).

Sleep/Wake Cycle

The sleep/wake cycle and its relationship to circadian rhythm disruption is important to the present study because the 2-2-1 shift schedule directly disrupts the sleep patterns of employees working the night shift, and the phase-advancing properties of the schedule may further disrupt the sleep/wake cycle. Sleep, in the entrained state, has essentially a 24-hour periodicity. Entrainment to this period is related to the more or less consistent timing of awaking in the morning and going to bed at night (Broughton, 1989).

Sleep duration was found to vary as a function of the time of sleep onset in relation to the phase of the circadian body temperature rhythm (Czeisler, Weitzman, Moore-Ede, Zimmerman, & Knauer, 1980). In free-running isolation studies, sleep duration was found to be longer when sleep onset times were near the temperature peak, and shorter when asleep times were closer to the temperature minimum. The mean sleep latency test demonstrated a rhythmic pattern with two distinct periods of maximum sleepiness occurring in the middle of the afternoon and the

middle of the night (Lavie, 1986; Richardson, Carskadon, Orau, & Dement, 1982). These findings have implications for shift workers on a schedule like the 2-2-1. If sleep is attempted when the temperature rhythm is rising, a person would have more difficulty falling asleep and the duration would be shorter.

Data reported on the sleep patterns of shift workers (Tepas, 1982) indicated that for workers on day shifts, sleep occurs just prior to their shift, with a sleep period between approximately 2300-0700. Afternoon and night shift workers, however, tended to sleep immediately following their shifts. Afternoon shift workers' sleep periods were found to occur between approximately 2430-0830, while night shift workers generally slept between the hours of 0900 and 1700. Tepas noted that the patterns were similar for permanent and rotating shift workers. Workers on the night shift exhibited the shortest sleep periods, while afternoon shift workers reported the longest total sleep times.

Phase Shift Studies

The term, "phase shift," refers to a shift in the phasic relationship of circadian rhythms to time. An example of such a shift can occur in the sleep/wake cycle as a result of a change in exogenous cues, such as that which occurs when crossing time zones, or as a result of shift work changes that result in a shift in the sleep/wake cycle. The sleep/wake cycle or pattern of sleep is measured by the time of sleep onset and termination (Webb, 1982). Phase advances or delays can occur in either or both of these measures, and may or may not result in a net change in sleep duration. Examples of laboratory-based procedures for phase shifting the sleep/wake cycle have included exposure to bright lights, administration of melatonin, and manipulating the rest/activity periods of subjects by asking them to sleep or work at particular times (OTA, 1991).

Taub and Berger (1976) reported a series of studies, in which they concluded that maintaining stable sleep schedules was of equal or greater importance than sleep duration for maintaining performance. In 1973, these authors reported a study to examine the effects of four consecutive weeks of phase-shifted sleep on performance. They allowed normal 7 to 8 hour sleep durations; however, they phase-advanced or phase-delayed sleep by 2 or 4 hours. Compared to a baseline sleep period from 2400 to 0800, all phase-shifted experimental conditions resulted in performance deficits on 2 tasks, calculation and vigilance. In follow-up studies with normal sleepers (7 to 8 hours per sleep period) and "habitual long sleepers" (9.5 to 10.5 hours per sleep period), Taub and Berger (1976) manipulated both phase and duration of sleep. In the phase-shifted conditions, sleep was advanced or delayed by 3 hours. All phase-shift conditions resulted in speed and accuracy decrements on a vigilance task, compared to performance after normal sleep periods for each individual. Other studies, particularly those on jet-lag (Wegmann & Klein, 1985; Monk, Moline, & Graeber, 1988) indicated that interruptions of sleep were more detrimental to performance than sleep loss.

Higgins et al. (1975) reported the effects of a 12-hour phase shift in the work day. Fifteen male subjects, ages 20-28, were asked to work on the Multiple Task Performance Battery (MTPB) during the day shift for four days. The MTPB provided a synthetic work environment in which the influence of various stressors, such as a phase shift of the sleep/wake cycle, on complex task performance could be systematically investigated in the laboratory. Sleep was scheduled for 2300-0600 during the first 4 days of the study, during which time subjects were working normal day shifts. Then, after only 3 hours of sleep (2100-2400) on the fifth night, the work schedule was shifted by 12 hours to a night shift, for a period of 10 days. During this period, subjects slept between 1030 and 1800. No changes in the total sleep quantity or quality were found on a subjective sleep survey as a result of the 12-hour phase shift. Performance on the MTPB, however, revealed that decrements in performance were found on the day following the short 3-hour sleep period: an 8% drop from the first session of the day to the last. In addition, performance on the first three days following the phase shift was relatively high during four of the five one-hour MTPB sessions, but fell off significantly during the last session. The end-of-the-day drop in performance was eliminated by days 4-6 after the phase shift, with little variation across each day. A reversal of the diurnal pattern of performance was shown during the last three days of

the study such that the performance peak after the phase shift was shifted 12 hours from the pre-phase shift peak. MTPB scores were generally lower on the last three days of the study, probably as a result of an end-of-the-study effect. Results from a subjective fatigue questionnaire revealed that the total fatigue index for each day was not changed by the 12-hour phase shift, but nine days were required for a complete reversal of the daily pattern reported for fatigue.

In a follow-up study, Higgins, Chiles, McKenzie, Funkhouser, Burr, Jennings, and Vaughan (1976) explored different alterations of the sleep/wake cycle. This study was designed as a laboratory analog of both a six-hour phase advance and a six-hour phase delay. Fifteen male volunteers (ages 21 to 30) spent five 10-hour days training on a Kugelmaschine and the MTPB. Then three days of baseline data were collected, during which time subjects slept from 2230-0600 and worked a two hours on, two hours off schedule on the MTPB, with work times beginning at 0800, 1200, 1600, and 2000. On the fourth day, each group spent time in the CAMI altitude chamber, equivalent to a flight from Oklahoma City to London, with a change of planes in Chicago. Three groups were established, such that one group slept from 0230-0600 on the fourth night, worked the schedule as noted above, and then returned to the pre-flight sleep time for the duration of the study. A second group experienced a 6-hour phase delay and began sleeping from 0430-1200 for the remainder of the study, with work times beginning at 1400, 1800, 2200, and 0200. The final group slept from 2030-2400 on the fourth night and then phase-advanced their sleep/wake cycle by 6 hours (1630-2400) for the remainder of the study, with work times beginning at 0200, 0600, 1000, and 1400. This final condition was analogous to a west-to-east flight or a quick-turn-around in a work schedule. Little difference was found in the physiological and biochemical measures between the six-hour-change groups. Rephasal time for body temperature for the six-hour phase shift was about half of that reported in the 1975 (Higgins et al.) study. Performance on the MTPB revealed that the phase-advanced group had the greatest deficit in performance, while the phase-delayed group had the best post-phase-shift performance. However, there was a confound in the number of hours slept after the "flight" to London, making it difficult to generalize these effects.

Age, Shift Work, and Biological Rhythms

Akerstedt and Torsvall (1981) suggest that after one's age reaches the mid-40s, shift work may suddenly become intolerable. Monk and Folkard (1985) suggested a framework of four possible contributory factors to aging effects related to shift work: 1) Cumulative adverse shift work effects; 2) general weakening of a worker's health and stress coping mechanisms; 3) the flattening of circadian rhythms with age; and 4) sleep tends to become more fragile and there is a tendency toward "morningness."

Foret, Bensimon, Benoit, and Vieux (1981) investigated the cumulative adverse effects of shift work in 750 oil refinery shift workers. Workers over age 40 reported poorer sleep and greater use of sleeping pills than younger workers. However, comparing workers within the same age group, workers with longer experience with shift work demonstrated poorer sleep patterns. Thus, the issue of age is sometimes confounded with length of time working shifts.

Weitzman, Moline, Czeisler, and Zimmerman (1982) reported that the gradual flattening of circadian rhythms with age has been well-documented. As noted in previous studies of biological rhythms, amplitude and phase lability can be associated with difficulty in coping with shift work. Weitzman et al. (1982) also discussed the deterioration of sleep patterns with increasing age. This is characterized by increased wakenings and a reduction in the total number of hours slept. Research has also demonstrated a shift in circadian phases with age toward a more morning type than evening type.

Mertens and Collins (1986) investigated the interaction of age, sleep deprivation, and altitude on complex performance on the MTPB. Older subjects (60-69) demonstrated somewhat lower performance and were more affected by workload. There was a significant interaction between sleep deprivation and altitude that was enhanced by increasing workload. However, age was not found to be an exacerbating factor.

In 1982, Webb and Levy reported age differences in performance after an extended period of sleep deprivation. In this study, performance of six younger men (age 18-22) was compared with performance of 10 older men (40-49) during the second night of sleep deprivation. Twelve experimental tests were administered. These included addition, visual search, word memory, word detection, reasoning, numerical estimation, object uses, remote associates tests, auditory vigilance, and line judgment. The data demonstrated that deprivation effects were greater in older subjects on tests emphasizing speed of performance, as well as those which did not.

Thus, as employees age, there is reason to expect that changes in sleep patterns and biological rhythms would result in increased difficulty in adapting to different shifts and shift schedules that result in partial sleep loss or circadian disruption.

Research Hypotheses

Based upon the application of chronobiological principles to the 2-2-1 schedule, it was hypothesized that the phase-advancing properties (counterclockwise rotation and quick-turn-arounds) would disrupt the sleep/wake cycle and result in cumulative partial sleep loss over the course of the 2-2-1 schedule. Specifically, it was hypothesized that:

a) Phase shifts in the sleep/wake cycle would be measurable in the asleep and awake times of the subjects during the 2-2-1 schedule.
b) Total sleep duration during the two quick-turn-arounds (between the second afternoon shift and the first day shift, and between the second day shift and the night shift) of the 2-2-1 schedule would be significantly less than total sleep duration when 14 hours were available between shifts (between the two afternoon shifts and between the two day shifts).
c) Total sleep time would be significantly less during a 2-2-1 work week when compared to total sleep time during a day shift work week.
d) Ratings of sleep quality would be significantly lower during the 2-2-1, especially on the second quick-turn-around (between the second day shift and the night shift) than sleep periods during day shift weeks.
e) Age differences in terms of the sleep/wake cycle would result in greater disruption for the older age group than for the younger age group.

The introduction has presented the theoretical background from which the 2-2-1 schedule was investigated, along with the hypotheses associated with the potential disruption of the sleep/wake cycle investigated in the study.

Methodology

A four-week protocol was designed to investigate the effects of the 2-2-1 quick-turn-around schedule. The first week of the protocol was allocated for subject adaptation to wearing physiological monitors 24 hours per day. The remainder of the protocol involved an A-B-A work schedule design whereby subjects worked straight days (0800-1630) during the second week of the study, the 2-2-1 schedule during the third week, and returned to a straight day schedule for the fourth week. A synthetic work environment was created by using the Multiple Task Performance Battery (MTPB). The protocol is represented in Table 2. (All times are based upon the 24-hour clock notation.)

To assess the effect of the schedule on performance, circadian rhythms and sleep/wake cycles, as well as subjective experiences of mood and sleepiness, a number of measures were collected during the study: 1) Performance on the MTPB; 2) physiological measures (core body temperature, heart rate, and activity level); 3) daily logs of sleep/wake times and sleep quality ratings; 4) neuroendocrine measures; and 5) mood and sleepiness scales. As previously noted, only the sleep data are presented here.

Subjects

Twenty male subjects were selected from two different age groups for this study. Ten subjects were between the ages of 30-35, with a mean age of 32.0 years. These subjects were termed the "Younger" group. The second group of 10 subjects was between the ages of 50-55, with a mean age of 52.4 years. These subjects comprised the "Older" group. The younger age range was selected to be representative of ATCSs after reaching full performance level, and the older age range was selected because ATCSs must stop controlling air traffic when they reach age 56. Subject selection was

Table 2

Study Protocol

DAYS	LABEL	PROTOCOL
Week1	**Baseline**	**Adaptation to Vitalog Monitor**
1	B1	0800-0900
2	B2	0800-0900
3	B3	0800-0900
4	B4	0800-0900
5	B5	0800-0900
6	W1	
7	W2	
Week2	**DAYS1**	**Straight Day Shift**
8	T1	0800-1630
9	T2	0800-1630
10	T3	0800-1630
11	T4	0800-1630
12	CD1	0800-1630
13	W3	
14	W4	
Week 3	**2-2-1**	**2-2-1 Schedule**
15	A1	1600-2430
16	A2	1400-2230
17	D1	0800-1630
18	D2	0600-1430
19	N	2400-0830
20	W5	
21	W6	
Week4	**DAYS2**	**Straight Day Shift**
22	CD2	0800-1630
23	CD3	0800-1630
24	CD4	0800-1630
25	CD5	0800-1630
26	CD6	0800-1200

LEGEND

B=Baseline
CD=Control
N=Night Shift
W=Weekend
DayA=Afternoon Shift
T=Training
D=Day Shift

restricted to males in order to minimize cyclic variations that might have interacted with or masked circadian variations in female subjects.

Human Subject Utilization Committee Reviews. The study protocol and subject consent forms were approved by the University of Oklahoma Institutional Review Board. In addition, the study protocol was reviewed and approved through the research review process of the FAA Office of Aviation Medicine.

Subject Recruitment and Reimbursement. Subjects were recruited and paid by a subject recruitment contractor. Subjects received $10 per hour for their participation on-site in the laboratory and $25 per day for wearing the physiological monitors. This totaled approximately $1900 per subject for completion of the study. Subjects were paid in two installments: upon completion of the first two weeks and upon completion of the study. All of the 20 subjects successfully completed the four-week protocol.

Subject Selection. Selection criteria were designed to match subjects on characteristics of the ATCS population. These included a medical examination, vision test, memory test, measures of intelligence, and questionnaires about sleep, activities, alcohol, and drug usage. Other selection criteria were designed to minimize attrition rates and included requirements for three-year local residency, three personal references, and an on-site interview with research staff. Smokers were excluded from the study. Subjects were also screened for caffeine, alcohol, and illicit drug use through administration of a drug use questionnaire. Subjects reporting excessive use of caffeine or alcohol, or any illicit drug use, were excluded from the study.

Initial screening was conducted by the contractor, during which time addresses and references were verified, and informed consent was obtained from each subject. Subsequent screening assessments were conducted on-site at CAMI. Research staff reviewed the informed consent with each subject individually, again at the time of the interview.

To ensure equivalence of health status with the ATCS population, subjects were required to meet the requirements for the FAA Class II medical examination (14 CFR, Part 67, Federal Aviation Regulations). The Class II examination included screening for normal cardiovascular functioning (blood pressure and heart rate), vision, color vision, and hearing. Vision requirements included assessment for 20/20 or better in each eye, without correction, or at least 20/100 in each eye separately, with correction to 20/20 or better. Subjects were assessed for normal visual fields and absence of pathology, as well as normal color discrimination ability. Examinations were conducted by the CAMI physician and clinic staff.

The Shipley Institute of Living Scale (Zachary, 1986) was used as a measure of intelligence. A minimum WAIS-R equivalent score of 104, or one standard deviation below the mean WAIS-R equivalent score of ATCSs (109.8, SD=5.9), was established for inclusion in this study, based upon a study of 414 students entering the FAA Academy ATCS Nonradar Screen (Della Rocco, Milburn, & Mertens, 1992). One exception was made to this criterion for one of the younger subjects with a WAIS-R equivalent score of 103. This subject was accepted in order to complete a group of five subjects by the designated group initiation date. The subject successfully met all other criteria.

The Digit Span subtest from the WAIS-R (Weschler, 1955) was also administered. A minimum capacity to remember five digits was required to successfully complete the MTPB code lock task. Subjects were required to recall a minimum of five digits on the Forward Digit Span subtest and four digits on the Backward Digit Span subtest. Prior studies from this laboratory using the Digit Span demonstrated a positive correlation between performance on the MTPB task and the Digit Span scores (personal communication with Dr. Henry Mertens).

Horne and Östberg's (1976) Morningness-Eveningness Questionnaire was administered to subjects at the time of screening, although it was not used to select subjects. Data were collected to assist in interpretation of the results.

Table 3 presents descriptive statistics from the Digit Span, Shipley Institute of Living Scale, and Morningness-Eveningness Questionnaire by age group. Analysis of variance comparing age group means revealed no significant differences between the groups on any of these measures.

Table 3

Descriptive Statistics from Subject Screening Questionnaires

	Younger Group		Older Group	
	Mean	SD	Mean	SD
Digit Span				
Forward	7.3	0.8	7.2	1.4
Backward	5.2	1.1	5.5	1.3
Shipley Institute of Living Scale				
Verbal	33.2	2.6	34.9	2.4
Abstract	32.6	3.1	32.2	4.0
Combined	66.2	4.1	67.1	4.8
WAIS-R equivalent	108.2	4.0	110.3	4.6
Morningness-Eveningness	57.1	8.7	62.9	5.5
Definite Morning	n=1		n=1	
Moderate Morning	n=4		n=7	
Neither Type	n=5		n=2	
Moderate Evening	n=0		n=0	
Definite Evening	n=0		n=0	

Subject Demographics. Seventeen of the 20 male subjects were Caucasian. Two subjects, one in each age group, were African-Americans. One subject in the Younger group was American Indian. Fifteen subjects were married. Half of the subjects reported prior military experience, eight of whom were in the Older group.

One subject held a Master's degree, eight subjects had completed a Bachelor's degree, and three subjects completed an Associate's degree. Five additional subjects reported having attended college. The remaining subjects had completed high school, with the exception of one subject who reported attaining a GED.

Eight subjects reported being currently employed at the time of their participation in the study. Three subjects from the Older group were retired. Six of the subjects reported previous employment in an aviation-related field. One subject in the Older group was a former air traffic controller with the Air Force.

Sleep Measures

Data on sleep times, duration, and quality were collected as self-report data in subjects' daily logbooks. The following measures were utilized from the logbooks: 1) asleep time; 2) awake time; and 3) sleep quality ratings. Total sleep time was computed as the difference between asleep time and awake time. These times were verified by visual inspection of the Vitalog accelerometer records and corrected in cases where the amount of activity conflicted with the self-reported times. Long awakenings during the reported sleep period (30 minutes or more) were subtracted from total sleep time.

Subjects reported sleep quality ratings in the daily logbooks upon arising. A sleep quality questionnaire used by NASA (Gander, Myhre, Graeber, Andersen, & Lauber, 1989) was modified for use in this study. The questions and scales were as follows: 1) "Falling asleep," from Not Difficult (1) to Difficult (5); 2)

"My sleep was," from Not Deep (1) to Deep (5); 3) "Arising was," from Not Difficult (1) to Difficult (5); and 4) "I now feel," from Not Rested (1) to Rested (5). The responses were rescored so that high scores on each question indicated good sleep. Then responses to all four questions were summed to give a possible high score of 20.

Procedures

The MTPB Laboratory was designed with five workstations. Thus, four groups of five subjects completed the protocol between September 1992 and February 1993. Each group of five subjects was balanced for subjects from the Older and Younger age groups (i.e., one group consisted of two subjects from the Older group and three from the Younger group, while the next group consisted of three subjects from the Older group and two from the Younger group).

Subjects reported to the laboratory from Monday through Friday, but continued wearing the portable physiological monitor throughout the weekends. Start dates for each of the groups varied due to various scheduling difficulties. Groups 1 and 3 began their protocols as scheduled on a Monday (Day 1). Group 2 did not begin, however, until Wednesday (Day 3), and Group 4 started the study on a Tuesday (Day 2).

Protocol. On the start date of the four-week protocol, subjects reported to the laboratory from 0800 to 1200 for orientation and training on use of the Vitalog physiological monitoring equipment. The orientation briefing included: 1) A brief summary of research issues about shift work, circadian rhythms, the ATCS's job, and previous studies validating the MTPB with ATCS students; 2) a formal briefing on the study protocol; 3) FAA facility and parking issues; and 4) potential applications of findings.

Subjects were instructed to treat their participation as a full-time job, to refrain from drinking alcohol, or taking any drugs or medications during the course of the experiment without informing the experimenter, and that deviation from the protocol could result in their termination from the study. Subjects were asked to maintain relatively stable sleeping and eating schedules. Phone numbers for the study staff were provided to each subject. Subjects were instructed to contact a researcher as soon as possible should a problem arise.

Subjects were issued a Vitalog portable monitor (Model 5000) following the orientation. A two-hour training session was provided on the appropriate use of the equipment. Subjects were issued activity logbooks, which had been modified from NASA logbooks (Gander et al., 1989), and instructed on maintaining daily records. Data collected in the logbooks included times associated with sleep and awakenings, sleep quality ratings, mood ratings, activities, naps, meals, caffeine intake, physical symptoms, times of urinations and bowel movements, and time and dosage of any medicine taken. The logbooks were used to verify study compliance.

For the remainder of the first week, subjects reported to the laboratory for approximately one hour at 0800 each day. Researchers met with each subject individually to assess any reported problems, verify completion of logbooks, and download physiological data to a computer from the Vitalog monitors.

During the second week, subjects began a three-week period of working 8.5 hour days at the laboratory, Monday through Friday. Week 2 consisted of straight day shifts from 0800-1630. Subjects began training on the MTPB on the first day of the second week. By the second day of that week, a daily protocol was established. Table 4 presents a sample daily protocol for the day shift. The procedures were the same during the 2-2-1 schedule.

Table 4

Sample Daily Experimental Protocol

Time	Activity
0800-0830	Arrive at the laboratory and download physiological data
0830-0835	Tracking and Questionnaires
0835-1035	MTPB Session 1
1035-1045	Tracking and Questionnaires
1045-1130	Meal Break
1130-1135	Tracking and Questionnaires
1135-1335	MTPB Session 2
1335-1345	Tracking and Questionnaires
1345-1405	Break
1405-1410	Tracking and Questionnaires
1410-1610	MTPB Session 3
1610-1615	Tracking and Questionnaires
1615-1630	Debriefing, supplies

Table 5

The Study 2-2-1 Shift Schedule

Day	2-2-1	Hours Between Shifts
1	1600-2430	13.5
2	1400-2230	9.5
3	0800-1630	13.5
4	0600-1430	9.5
5	0000-0830	---

During the third week of the protocol, the subjects worked a 2-2-1 shift (Melton, 1982). The daily protocol detailed in Table 4 was followed during all shifts. The 2-2-1 was scheduled as shown in Table 5.

Subjects returned to working straight day shifts (0800-1630) during the fourth and final week of the protocol. Only two MTPB sessions were completed on the final day of the study, and the remaining time was used for collecting equipment and debriefing.

Design and Data Analyses

The study was a mixed-model design with one between-groups factor and two repeated-measures factors. The between-groups factor was age group. The within-subjects factors were Day of the study and Session (or Sample in the case of neuroendocrine measures). Analyses and factorial models were specific to each dependent measure. Data analyses were conducted utilizing the SPSS statistical package, version 4.1 for VAX/VMS. For the majority of the analyses the SPSS MANOVA procedure for repeated measures was employed.

Multiple comparisons were conducted utilizing procedures prescribed by Toothaker (1991) when significant interactions or main effects resulted from the MANOVA. The multiple comparison procedure (MCP) involved a series of paired t-tests on planned comparisons. The comparisons were developed as a result of application of chronobiological principles to the 2-2-1 work schedule. The control for probability of Type I error was established by referring the t-value to a Dunn critical value with parameters df = J(n-1) and C = K(K-1)/2, where J equals the number of between-subject groups, n equals the number of subjects per group, and K equals the number of repeated measurements for computation of all pairwise comparisons. If fewer than all possible pairwise comparisons were computed, then C equaled the number of planned comparisons (Toothaker, 1991). Each analysis of a dependent measure utilized a slightly different factorial design, based upon when measures were collected and the specific hypotheses tested, as follows.

To test the hypothesis that the 2-2-1 work schedule resulted in a phase advance in the sleep/wake cycle and cumulative partial sleep loss, two-way, between-subjects, repeated-measures, 2 x 16 MANOVAs were computed for sleep measures where the two age groups were the between-groups factor and 16 sleep periods of the study were the repeated-measures factor. The 16 sleep periods were selected to parallel the MTPB performance analyses. Therefore, the MANOVA included sleep periods from day CD1 through CD6 (see Table 2) and provided for comparison of day shifts to each day of the 2-2-1, as well as the weekend days of the study. Analyses were computed for 1) asleep time, 2) awake time, 3) sleep duration, and 4) sleep quality ratings. Planned comparisons for asleep and awake times and duration included: 1) Comparison from one sleep period to the next, beginning with Saturday before the 2-2-1 week through Thursday afternoon's sleep, to determine phase shifts from one sleep period to the next, 2) CD1, a day shift, to the weekend prior to the 2-2-1, 3) weekend sleeps before and after the 2-2-1, and 4) the first two sleep periods of the recovery week to CD1, and each other. There were a total of 12 comparisons. A Dunn's critical value of 3.48 for 15 comparisons with 15 degrees of freedom was used.

To assess cumulative partial sleep loss between day shift weeks and the 2-2-1, mean differences between total sleep time during DAYS1 shifts to total sleep time during the 2-2-1 shift, for 1) the total seven-day period, 2) the five days of work and 3) non-work days were analyzed utilizing 2 (Age) x 2 (Week) MANOVAs.

Planned comparisons for sleep quality ratings involved comparing 1) a day shift sleep, T4-CD1, to a) the weekends before and after the 2-2-1, b) each day of the 2-2-1, and c) W6-CD2 to examine recovery from the 2-2-1 and 2) a weekend sleep (CD1-W3) to each day of the 2-2-1. There were a total of 15 comparisons. A Dunn's critical value of 3.48 for 15 comparisons and 15 degrees of freedom was used for these comparisons.

RESULTS

To test the hypothesis that working the 2-2-1 shift would result in a phase advance of the sleep/wake cycle and cumulative partial sleep loss, three sets of measures were analyzed on the sleep of subjects during the study: *sleep patterns, sleep duration,* and *subjective sleep quality ratings.* Data from two subjects, one from each age group, were not included in analyses of Asleep and Awake Times. In the case of the Older subject, he did not sleep following the night shift, and therefore, had no Awake or Asleep Times. In the case of the Younger subject, sleep patterns were affected by transportation requirements during two weeks of the study. Both subjects were included in analyses of sleep duration and sleep quality ratings. Results of the analyses were as follows.

Table 6

Means and Standard Deviations for Asleep Times

		Younger		Older		Overall	
		Mean	SD	Mean	SD	Mean	SD
SLEEP PERIOD	**LABEL**						
Baseline							
Thur-Fri	B4-B5	2336	1.2	2243	0.7	2309	1.1
Weekend 1							
Fri-Sat	B5-W1	0040	1.9	2250	2.0	2345	2.1
Sat-Sun	W1-W2	0019	1.2	2340	1.5	2400	1.4
DAYS1							
Sun-Mon	W2-T1	2324	0.8	2236	1.0	2300	1.0
Mon-Tue	T1-T2	2249	0.9	2222	1.0	2236	1.0
Tue-Wedy	T3	2318	1.0	2242	0.6	2300	0.9
Wed-Thur	T3-T4	2249	0.9	2251	0.5	2251	0.7
Thur-Fri	T4-CD1	2319	1.3	2222	0.8	2251	1.2
Weekend 2							
Fri-Sat	CD1-W3	0021	1.6	2324	1.1	2352	1.4
Sat-Sun	W3-W4	0046	1.8	2336	1.8	0011	1.8
2-2-1							
Sun-Mon	W4-A1	0031	1.6	2343	1.7	0007	1.6
Mon-Tue	A1-A2	0207	0.8	0149	0.8	0158	0.8
Tue-Wed	A2-D1	0018	1.0	2352	0.5	0005	0.8
Wed-Thur	D1-D2	2154	1.3	2127	0.9	2140	1.1
Thursday	D2-N	1649	1.7	1652	1.2	1651	1.4
Friday	Post N	1125	2.8	0944	0.9	1034	2.2
Weekend 3							
Fri-Sat	N-W5	0109	1.7	2307	1.6	0009	1.9
Sat-Sun	W5-W6	0052	1.6	2352	1.7	0022	1.7
DAYS2							
Sun-Mon	W6-CD2	0008	1.2	2213	1.2	2310	1.5
Mon-Tue	CD2-CD3	2321	1.0	2215	0.7	2248	1.0
Tue-Wed	CD3-CD4	2307	1.1	2236	0.8	2252	1.0
Wed-Thur	CD4-CD5	2311	1.0	2210	1.0	2240	1.1
Thur-Fri	CD5-CD6	2356	1.2	2226	1.1	2311	1.4

Sleep/Wake Cycle

To assess the extent to which the 2-2-1 schedule disrupted the sleep/wake cycle and served to phase advance subjects working the schedule, the average Asleep and Awake times were computed, and the changes induced by the 2-2-1 work week were examined. Tables 6 and 7 present the means and standard deviations for Asleep and Awake times. Data were included from the end of the Baseline week (after all groups had started the protocol) through the end of DAYS2, the final week of the study, including weekends and the sleep periods before and after the Night shift, but not including any "naps" that were taken in addition to the major sleep period.

Table 7

Means and Standard Deviations for Awake Times

		Younger		Older		Overall	
		Mean	SD	Mean	SD	Mean	SD
SLEEP PERIOD	**LABEL**						
Baseline							
Thur-Fri	B4-B5	0614	1.4	0554	0.6	0604	1.1
Weekend 1							
Fri-Sat	B5-W1	0757	2.1	0718	1.3	0738	1.8
Sat-Sun	W1-W2	0849	2.8	0745	1.0	0817	2.1
DAYS1							
Sun-Mon	W2-T1	0530	1.2	0548	0.4	0539	0.9
Mon-Tue	T1-T2	0549	0.7	0543	0.6	0546	0.7
Tue-Wed	T2-T3	0549	0.7	0545	0.3	0546	0.5
Wed-Thur	T3-T4	0545	0.7	0548	0.3	0546	0.6
Thur-Fri	T4-CD1	0600	0.8	0552	0.4	0556	0.6
Weekend 2							
Fri-Sat	CD1-W3	0820	2.7	0751	1.4	0806	2.1
Sat-Sun	W3-W4	0852	2.4	0807	0.9	0830	1.8
2-2-1							
Sun-Mon	W4-A1	0817	2.2	0704	1.0	0740	1.8
Mon-Tue	A1-A2	0845	2.4	0821	1.3	0833	1.9
Tue-Wed	A2-D1	0604	0.7	0555	0.2	0600	0.5
Wed-Thur	D1-D2	0431	0.4	0415	0.3	0423	0.4
Thursday	D2-N	1958	2.0	2056	1.9	2027	2.0
Friday	Post N	1534	2.1	1304	1.9	1419	2.3
Weekend 3							
Fri-Sat	N-W5	0857	2.4	0756	1.5	0826	2.0
Sat-Sun	W5-W6	0915	1.8	0813	1.2	0844	1.6
DAYS2							
Sun-Mon	W6-CD2	0613	0.2	0545	0.3	0558	0.4
Mon-Tue	CD2-CD3	0603	0.6	0522	0.6	0543	0.7
Tue-Wed	CD3-CD4	0601	0.8	0551	0.5	0557	0.6
Wed-Thur	CD4-CD5	0549	1.0	0555	0.3	0552	0.7
Thur-Fri	CD5-CD6	0612	0.6	0551	0.6	0601	0.6

Figure 1 presents a graphic representation of one subject's sleep/wake patterns, selected from the younger age group as representative of the effects of the 2-2-1 schedule on the sleep/wake cycle. Work times have been displayed, along with sleep times, to provide a reference.

Figure 1 reveals the disruption of the sleep pattern by the 2-2-1 schedule. An Age x Days between groups repeated-measures MANOVA was computed for the Asleep and Awake times to assess the extent to which the sleep patterns were altered. The analysis included those sleep periods occurring between days CD1 and CD6, including weekends and the afternoon sleep before the night shift, resulting in a 2 x 16 MANOVA. Tables 8 and 9 present the results of the MANOVA for Asleep and Awake Times, respectively.

Results of the MANOVA for Asleep Time revealed a significant main effect of Age, $\underline{F}(1, 16)=7.25$, $\underline{p}<.001$, as well as Day, $\underline{F}(15, 240)=186.04$, $\underline{p}<.001$. The simple main effect of Age indicated that the Older group ($\underline{M}$=2151) went to sleep approximately one hour before the Younger group ($\underline{M}$=2250) on the average throughout the study. Planned multiple comparisons revealed the following phase-shifting patterns of Asleep Time due to the 2-2-1:

1) Asleep time was significantly later (phase delayed) on the A1-A2 sleep ($\underline{M}$=0158) than the W4-A1 sleep ($\underline{M}$=0007) by approximately two hours, $\underline{t}(16)=4.62$, $\underline{p}<.05$, as a result of working until 0030 on the A1 shift.
2) There were three significant advances in the Asleep times of the three sleep periods following the phase delay.

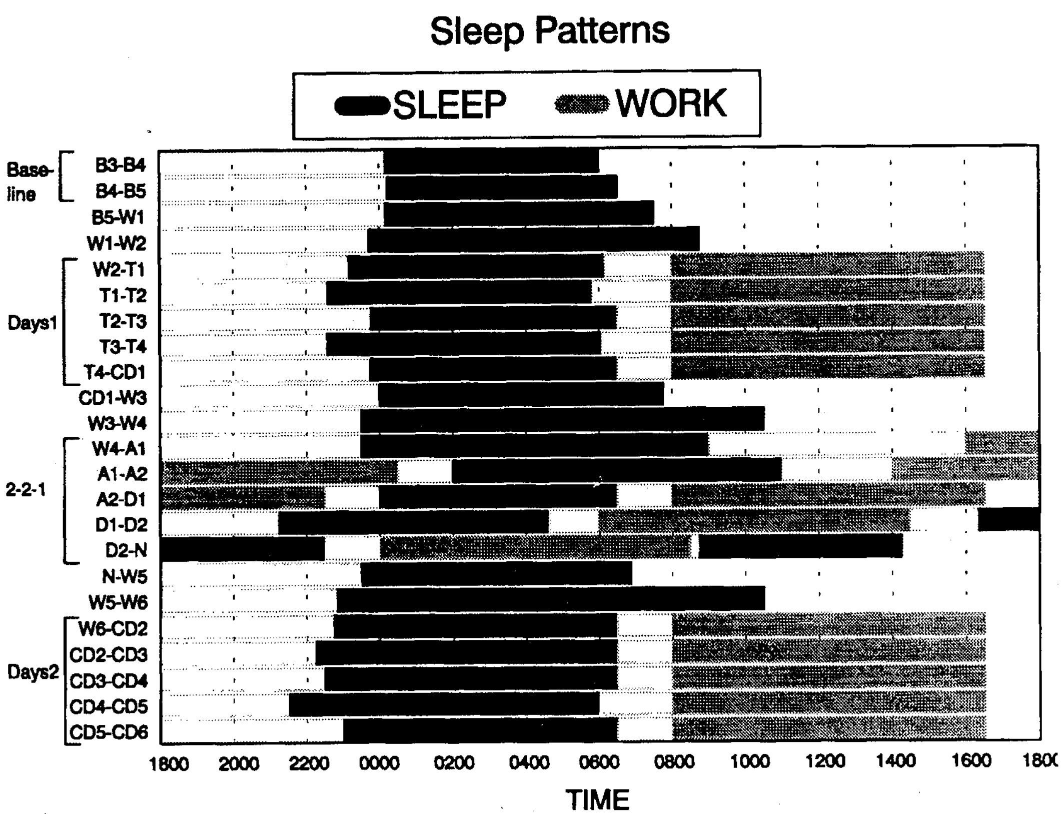

Figure 1. Sleep/wake patterns and work times for one subject from the younger age group. Data are included for the duration of the study protocol from the end of the Baseline week.

Table 8

MANOVA Summary Table for Asleep Times

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	70.01	70.01	7.25*
Between Subjects	16	154.59	9.66	
Day of Shift	15	3670.09	244.67	186.04**
Age by Day	15	23.20	1.55	N.S.
Within Subjects	240	315.64	1.32	

*p<.05
**p<.001

Table 9

MANOVA Summary Table for Awake Times

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	20.58	20.58	N.S.
Between Subjects	16	199.30	12.46	
Day of Shift	15	4308.99	287.27	225.29**
Age by Day	15	36.59	2.44	1.91*
Within Subjects	240	306.02	1.28	

*p<.05
**p<.001

a) Asleep time was significantly earlier (phase-advanced) on the A2-D1 sleep (M=0005) than on the A1-A2 sleep (M=0158) by approximately two hours, $t(16)=13.61$, $p<.05$.
b) Asleep time for the D1-D2 sleep period (M=2140) was significantly earlier than the A2-D1 sleep period (M=0005), the first quick-turn-around, by approximately two and one-half hours, $t(16)=8.71$, $p<.05$.
c) Asleep time for the D2-N sleep period (M=1651), the second quick-turn-around, was significantly earlier than the D1-D2 sleep period (M=2140) by approximately five hours, $t(16)=11.61$, $p<.05$.

3) There was no significant difference in Asleep times between the weekend nights (CD1-W3 [M=2352] or W3-W4 [M=0011]) and Sunday night before the 2-2-1 (W4-A1 [M=0007]), suggesting that the night before the start of the 2-2-1 was treated like a third weekend night, in terms of Asleep time.
4) No significant differences were found among weekend Asleep times either before or after the 2-2-1.

For Awake time, there was a significant Age x Day interaction, $F(15, 240)= .91$, $p<.05$, as well as a main effect for Day, $F(15, 240)=225.29$, $p<.001$. None of the planned comparisons for Age x Day reached statistical

significance, indicating that the interaction was not within the planned investigation of effects of the 2-2-1. The results of the planned comparisons for the Day effects indicated the following:

1) Subjects awoke significantly later on the weekends than on the day shift. Awake time on the Saturday morning (CD1-W3) before the 2-2-1 ($\underline{M}$=0806) was significantly later than the Awake time on T4-CD1 ($\underline{M}$=0556) by approximately two hours, $\underline{t}(16)=4.96$, $\underline{p}<.05$. Similar patterns were found when comparing CD1 to Awake times on the remaining weekend days. Awake time on W3-W4 before the 2-2-1 ($\underline{M}$=0830) was approximately two and one-half hours later than CD1 ($\underline{M}$=0556), $\underline{t}(16)=7.06$, $\underline{p}<.05$. Compared to T4-CD1, the W4-W5 ($\underline{M}$=0826), $\underline{t}(16)=6.27$, $\underline{p}<.05$, and W5-W6 ($\underline{M}$=0843), $\underline{t}(16)=8.76$, $\underline{p}<.05$, morning Awake times were also significantly later.
2) There was no significant difference between the Awake times on W4-A1 and the other days of the weekend before the 2-2-1, suggesting again that the Sunday night before the 2-2-1 was treated like another weekend night, in terms of Awake time.
3) There were three significant advances in Awake time associated with the advancing Asleep times during the 2-2-1.
   a) Awake time for the first quick-turn-around sleep, A2-D1, ($\underline{M}$=0600) was significantly earlier than Awake time for the A1-A2 sleep ($\underline{M}$=0833) by approximately 2.5 hours, $\underline{t}(16)=6.27$, $\underline{p}<.05$.
   b) Awake time was also significantly earlier for the D1-D2 sleep ($\underline{M}$=0423) than for the A2-D1 sleep ($\underline{M}$=0600) by approximately 1.5 hours, $\underline{t}(16)=11.04$, $\underline{p}<.05$.
   c) Finally, Awake time on the second quick-turn-around sleep, before the night shift (D2-N) on Thursday afternoon ($\underline{M}$=2027) was significantly earlier than Awake time for the D1-D2 sleep ($\underline{M}$=0423) by approximately eight hours, $\underline{t}(16)=34.30$, $\underline{p}<.05$.
4) There were no significant differences in Awake times between weekend mornings before or after the 2-2-1 shift.
5) When subjects returned to the Day shift on CD2 after the 2-2-1, the Awake time was significantly earlier ($\underline{M}$=0558) compared to the Awake time for the W5-W6 sleep ($\underline{M}$=0844) by approximately 2.75 hours, $\underline{t}(16)=8.23$, $\underline{p}<.05$.

Finally, the sleep patterns on the Friday following the Night shift were highly variable. Of the 20 subjects, 19 slept on Friday during the day. Of those, 16 (seven Younger, nine Older) slept in the morning with Asleep times ranging from 0840-1115, and Awake times ranging from 1100-1700. The remaining subjects (three younger) slept in the afternoon, with Asleep times ranging from 1320-1620 and Awake times ranging from 1800-1840. One subject from the Older group, who remained awake during the day on Friday, fell asleep at 0050 on Saturday.

Sleep Duration

Measures of sleep duration were assessed to determine whether or not the 2-2-1 resulted in cumulative partial sleep loss. Means and standard deviations for mean sleep duration (MSD) are presented in Table 10.

Figure 2 presents MSD by day and week of the study. Figure 2 shows that daily sleep duration was relatively stable during the Baseline (Week 1), DAYS1 (Week 2), and DAYS2 (Week 4), but exhibited a more erratic pattern during the 2-2-1.

Table 11 presents the MANOVA Summary Table for MSD.

The results of the 2 x 16 MANOVA revealed a significant main effect of Day, $\underline{F}(15, 270)=28.08$, $\underline{p}<.001$ on MSD. Planned multiple comparisons revealed the following:

1) Weekend MSDs were generally longer than work day MSDs. MSD was significantly longer for the W3-W4 sleep ($\underline{M}$=8.5 hours) before the 2-2-1, $\underline{t}(18)=3.59$, $\underline{p}<.05$, and the N-W5 sleep ($\underline{M}$=8.2 hours) following the 2-2-1, $\underline{t}(18)=3.48$, $\underline{p}<.05$, than the T4-CD1 sleep period before the Day shift ($\underline{M}$=7.0 hours).
2) The Sunday night before the 2-2-1 (W4-A1) was treated like a weekend night. MSD on W4-A1 ($\underline{M}$=7.6 hours) was not significantly different from W3-W4 ($\underline{M}$=8.5 hours), but was significantly longer than the following night's (A1-A2) sleep ($\underline{M}$=6.4 hours), $\underline{t}(18)=3.52$, $\underline{p}<.05$.

Table 10

Means and Standard Deviations for Sleep Duration

		Younger		Older		Overall	
		Mean	SD	Mean	SD	Mean	SD
SLEEP PERIOD	**LABEL**						
Baseline							
Thur-Fri	B4-B5	6.5	1.6	7.2	0.7	6.8	1.2
Weekend 1							
Fri-Sat	B5-W1	7.6	1.9	8.3	1.6	7.9	1.7
Sat-Sun	W1-W2	8.5	1.4	7.8	1.5	8.2	1.5
DAYS1							
Sun-Mon	W2-T1	6.0	1.1	7.0	1.1	6.5	1.2
Mon-Tue	T1-T2	7.0	0.8	7.1	1.3	7.0	1.1
Tue-Wed	T2-T3	6.4	0.9	6.9	0.7	6.7	0.8
Wed-Thur	T3-T4	6.7	0.9	6.9	0.6	6.8	0.8
Thurs-Fri	T4-CD1	6.6	1.5	7.3	0.9	7.0	1.2
Weekend 2							
Fri-Sat	CD1-W3	8.2	1.9	7.9	1.2	8.1	1.5
Sat-Sun	W3-W4	8.5	2.0	8.4	1.4	8.5	1.7
2-2-1							
Sun-Mon	W4-A1	7.9	1.7	7.2	1.3	7.6	1.5
Mon-Tues	A1-A2	6.4	1.8	6.3	1.1	6.4	1.5
Tues-Wed	A2-D1	5.7	1.1	5.9	0.6	5.8	0.9
Wed-Thurs	D1-D2	6.6	1.2	6.6	0.9	6.6	1.0
Thursday	D2-N	3.5	1.6	4.0	1.7	3.7	1.6
Friday	Post N	4.1	1.4	3.0	1.6	3.5	1.6
Weekend 3							
Fri-Sat	N-W5	7.7	1.6	8.8	1.3	8.2	1.5
Sat-Sun	W5-W6	8.4	1.7	8.2	1.9	8.3	1.8
DAYS2							
Sun-Mon	W6-CD2	6.1	1.1	7.4	1.2	6.8	1.3
Mon-Tues	CD2-CD3	6.5	1.1	6.9	0.9	6.7	1.0
Tues-Wed	CD3-CD4	6.9	1.2	7.0	1.1	6.9	1.1
Wed-Thurs	CD4-CD5	6.6	1.2	7.5	1.2	7.1	1.3
Thurs-Fri	CD5-CD6	6.4	1.4	7.2	1.2	6.8	1.3

Table 11

MANOVA Summary Table for Mean Sleep Duration

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	3.66	3.66	N.S.
Between Subjects	18	158.81	8.82	
Day of Shift	15	615.62	41.04	28.08**
Age by Day	15	30.80	2.05	N.S.
Within Subjects	270	394.63	1.46	

**p<.001

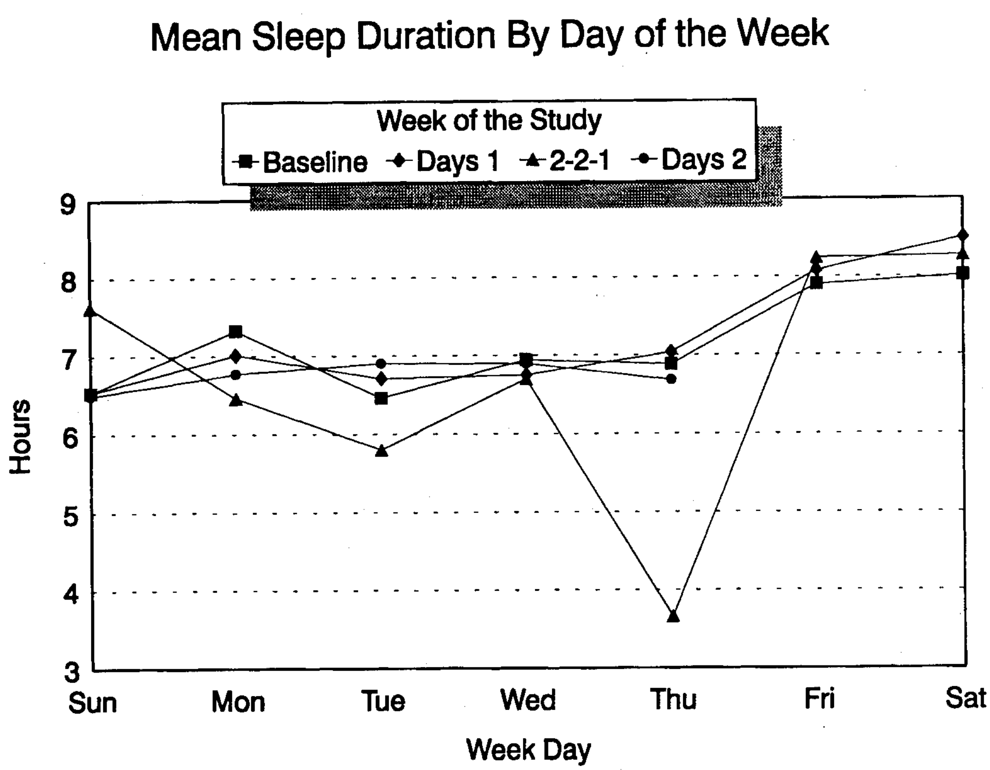

Figure 2. Mean Sleep Duration by day of the week for each of the four weeks of the study over both age groups.

3) There were no significant differences in MSD in the middle of the 2-2-1 week, comparing A1-A2 ($\underline{M}$=6.4 hours), A2-D1 ($\underline{M}$=5.8 hours), and D1-D2 ($\underline{M}$=6.6 hours) nights to the T4-CD1 sleep or among each of those three nights during the 2-2-1. Of note is the fact that, although the MSD dropped on A2-D1, the first quick-turn-around, it was not a significant drop.
4) Significant sleep loss did occur just prior to the Night shift on the Thursday afternoon sleep period. The MSD on Thursday afternoon was only 3.7 hours and was significantly less than D1-D2 sleep ($\underline{M}$=6.6 hours), $\underline{t}(18)=7.69, \underline{p}<.05$.
5) MSDs on the weekend following the 2-2-1 (N-W5 and W5-W6) were not significantly longer than the corresponding weekend days prior to the 2-2-1 (CD1-W3 and W3-W4).

To determine if the 2-2-1 schedule resulted in cumulative partial sleep loss, subjects' MSDs were assessed in a manner similar to a previous ATCS sleep study (Saldivar, 1977), which involved three comparisons between DAYS1 and the 2-2-1 weeks: 1) the seven-day week, 2) the five-day work week, and 3) non-work days. Sleep durations for each period were calculated for the sleep prior to the work or non-work period. Therefore, sleep durations used to calculate the five-day work week included Sunday night through Thursday. During the DAYS1 week, the Thursday sleep period was Thursday night; however, during the 2-2-1, the sleep period was Thursday afternoon prior to the night shift. Sleep obtained after the night shift on Friday morning was included in the MSD for the seven-day week, but not for the five-day work week or the non-work days. Non-work days included Friday and Saturday nights. Table 12 presents descriptive MSD data for each of the three time frames by age group and by shift schedule (DAYS1 and the 2-2-1).

A 2 x 2 MANOVA with age as the between-subjects independent variable and mean sleep duration as the dependent, repeated measure across the two shift weeks, was computed for each of the three comparisons. Comparison of the MSD for the sleep periods of the five work days (Sunday through Thursday) revealed that subjects slept significantly less on the average during the 2-2-1 shift ($\underline{M}$=6.05 hours), $\underline{F}(1, 18)=11.77$, $\underline{p}<.01$, than during DAYS1 ($\underline{M}$=6.80 hours). However, comparison of MSD across the seven days for Sunday through Saturday night revealed no

Table 12

Means and Standard Deviations for Mean Sleep Duration by Age Group and Shift Schedule

	DAYS1 (Week 2)		2-2-1 (Week 3)	
	Mean (hours)	**SD**	**Mean (hours)**	**SD**
5 Work Week Days	6.80	.69	6.05*	.83
Younger Group	6.58	.65	6.09	1.04
Older Group	7.03	.69	6.01	.62
7 Work and Non-work Days	7.23	.63	7.19	.86
Younger Group	7.10	.64	7.24	1.05
Older Group	7.36	.61	7.14	.69
Non-Work Days	8.29	1.35	8.26	1.29
Younger Group	8.40	1.74	8.04	1.41
Older Group	8.19	.89	8.48	1.18

significant differences due to the shift schedule worked. No significant differences were found in MSD between the non-work days (Friday and Saturday nights) following either shift schedule, suggesting that the sleep debt, accumulated during the 2-2-1 schedule, was made up by sleep following the night shift on Friday. No age differences were found.

Sleep Quality Ratings

Subjective ratings of sleep quality were recorded for each sleep period, except the Friday morning following the Night shift. Two subjects, one from each age group, were excluded from the following data for failing to complete all ratings. Ratings for the four 5-point scale items were summed for a total of twenty possible points. Lower ratings represented poor sleep quality; higher ratings represented good sleep quality. Means and standard deviations for combined sleep quality ratings are presented in Table 13.

Table 14 presents the MANOVA Summary Table for the combined Sleep Quality Ratings.

The results of the 2 x 16 MANOVA for combined sleep quality ratings revealed a main effect for Day, $\underline{F}(14, 224)=7.22$, $\underline{p}<.001$. Planned multiple comparisons revealed:

1) Compared to a day shift sleep (T4-CD1), only the 2-2-1's second quick-turn-around D2-N sleep quality ($\underline{M}=11.1$) was rated significantly lower than the T4-CD1 sleep ($\underline{M}=14.3$), $\underline{t}(16)=4.56$, $\underline{p}<.05$.
2) Comparison of each of the 2-2-1 work days with a weekend (CD1-W3) sleep ($\underline{M}=16.2$) revealed significantly lower sleep quality ratings for three of the five 2-2-1 sleep periods: A1-A2 ($\underline{M}=13.3$), $\underline{t}(16)=4.28$; D1-D2 ($\underline{M}=13.2$), $\underline{t}(16)=3.67$; D2-N ($\underline{M}=11.1$), $\underline{t}(16)=6.35$, $\underline{p}<.05$, indicating that for three of the 2-2-1 sleep periods, sleep quality was rated poorer than weekend sleep. This was

Table 13

Means and Standard Deviations for Combined Sleep Quality Ratings

		Younger		Older		Overall	
		Mean	SD	Mean	SD	Mean	SD
SLEEP PERIOD	**LABEL**						
DAYS1							
Thurs-Fri	T4-CD1	14.1	1.9	14.4	2.8	14.3	2.3
Weekend 2							
Fri-Sat	CD1-W3	16.6	2.7	15.9	3.3	16.2	2.9
Sat-Sun	W3-W4	15.1	2.2	15.9	1.7	15.5	1.9
2-2-1							
Sun-Mon	W4-A1	15.1	3.4	14.7	2.6	14.9	3.0
Mon-Tues	A1-A2	13.4	2.7	13.1	2.8	13.3	2.7
Tues-Wed	A2-D1	11.9	3.9	14.4	2.4	13.2	3.4
Wed-Thurs	D1-D2	14.3	3.0	12.1	3.2	13.2	3.2
Thursday	D2-N	11.7	2.4	10.4	2.2	11.1	2.4
Friday	Post N	—	—	—	—	—	—
Weekend 3							
Fri-Sat	N-W5	15.4	2.8	16.3	2.2	15.9	2.5
Sat-Sun	W5-W6	16.2	2.2	16.3	1.3	16.3	1.8
DAYS2							
Sun-Mon	W6-CD2	13.4	4.2	13.7	2.9	13.6	3.5
Mon-Tues	CD2-CD3	13.9	3.1	14.9	1.7	14.4	2.5
Tues-Wed	CD3-CD4	14.1	2.7	15.7	2.8	14.9	2.8
Wed-Thurs	CD4-CD5	14.6	2.2	14.8	3.1	14.7	2.6
Thurs-Fri	CD5-CD6	14.1	3.9	14.3	2.3	14.2	3.1

Table 14

MANOVA Summary Table for Sleep Quality Ratings

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Age	1	2.70	2.70	N.S.
Between Subjects	16	774.13	48.38	
Day of Shift	14	484.53	34.61	7.22**
Age by Day	14	81.91	5.85	N.S.
Within Subjects	224	1073.42	4.79	

**p<.001

not true for either 1) the Day shift sleep, T4-CD1, or 2) A2-D1, the first quick-turn-around, neither of which was found to be rated significantly lower than the weekend ratings.

Each of the sleep quality rating categories was assessed to determine which dimensions were identified by the subjects as the source of the perceived sleep disruptions. MANOVAs on each of the four questions resulted in a significant main effect for Day, as follows: 1) Difficulty in falling asleep $\underline{F}(4, 224)= 3.18$, $\underline{p}<.001$; 2) How deep was sleep, $\underline{F}(14, 224)=6.62$, $\underline{p}<.001$; 3) Difficulty arising, $\underline{F}(14, 224)=3.44$; and 4) Rested feeling $\underline{F}(14, 224)=5.90$, $\underline{p}<.001$. Planned comparisons on each of the four questions revealed the following:

1) For T4-CD1, a day shift sleep, compared to D2-N, the quick-turn-around to the night shift, results revealed that the afternoon sleep on D2-N ($\underline{M}=2.22$) was not rated as deep as the T4-CD1 sleep ($\underline{M}=3.78$), $\underline{t}(16)=5.50$, $\underline{p}<.05$. No differences were found, however, for any of the other three sleep rating items.
2) For a weekend sleep, CD1-W3, compared to the sleep periods associated with the 2-2-1 shift, results revealed that:
   a) For the A1-A2 sleep, subjects reported significantly poorer ratings for difficulty arising ($\underline{M}=2.83$) and for how rested they felt ($\underline{M}=2.94$) than for CD1-W3 ratings of difficulty arising ($\underline{M}=4.17$), $\underline{t}(16)=4.26$, $\underline{p}<.05$; and how rested they felt ($\underline{M}=4.0$), $\underline{t}(16)=4.78$, $\underline{p}<.05$, respectively.
   b) For the D1-D2 sleep, subjects reported significantly greater difficulty falling asleep ($\underline{M}=3.06$) than for CD1-W3 ($\underline{M}=4.33$), $\underline{t}(16)=3.86$, $\underline{p}<.05$.
   c) For the afternoon D2-N sleep, subjects reported poorer sleep quality ratings on all four questions than for the weekend, CD1-W3. Falling asleep was rated more difficult on D2-N ($\underline{M}=2.94$) than on CD1-W3 ($\underline{M}=4.33$), $\underline{t}(16)=4.74$, $\underline{p}<.05$. Subjects reported deeper sleep on CD1-W3 ($\underline{M}=3.72$) than on D2-N ($\underline{M}=2.22$), $\underline{t}(16)=4.34$, $\underline{p}<.05$. Arising was rated more difficult on D2-N ($\underline{M}=3.44$) than on W3-W4 ($\underline{M}=4.17$), $\underline{t}(16)=3.71$, $\underline{p}<.05$. And finally, subjects reported feeling significantly less rested on D2-N ($\underline{M}=2.50$) than on CD1-W3 ($\underline{M}=4.00$), $\underline{t}(16)=4.60$, $\underline{p}<.05$.
   d) One additional finding was that subjects reported feeling significantly less rested on A2-D1 ($\underline{M}=2.78$) than on CD1-W3 ($\underline{M}=4.00$), $\underline{t}(16)=4.27$, $\underline{p}<.05$.
3) Sleep ratings for W6-CD2, the sleep prior to the first day shift after the 2-2-1, were no different on any of the items than for T4-CD1, suggesting no extended effects of the 2-2-1 beyond the weekend.

Napping Data

The calculation of sleep duration did not include naps or sleeps taken aside from the major sleep of the day. However, napping data were collected and are summarized as follows:

Baseline: A total of 23 naps (by 14 subjects) were taken from days B3-B5 during the baseline week. These naps occurred on days when subjects only had to report to the lab for one hour per day. Thirteen of the naps were taken by subjects in the Younger age group (M=1.5 hours), and ten were taken by subjects in the Older age group (M=1.1 hours).

DAYS1. In contrast, only two naps were reported during the five days of DAYS1. A 1.5-hour nap was taken by a Younger subject and a .25-hour nap was taken by an Older subject.

2-2-1 Week. Nine naps (by eight subjects) were reported during the 2-2-1 work week. Six of these were taken on A1, the day of the first afternoon shift. The remaining three were taken on A2, the day of the second afternoon shift. Of these naps, four were taken by Younger subjects (M=1.9 hours) and five by Older subjects (M=.75 hours).

DAYS2. Six naps (by four subjects) were reported during DAYS2. The mean nap time for the Younger subjects (n=2) was 1.25 hours. One Older subject took a .25-hour nap, while the other did not report the actual length of the nap.

Weekends. Seven naps were reported for the weekend before DAYS1, eight were reported for the weekend before the 2-2-1, and six were reported for the weekend before DAYS2. Of these 21 naps, nine were taken by five Younger subjects (M=1.7 hours) and 12 were taken by six Older subjects (M=1.2 hours). The number of naps reported did not increase on the weekend after the 2-2-1 work week.

DISCUSSION

This report presented the results of an investigation of a unique, rapidly-rotating shift schedule, the 2-2-1, commonly used by Air Traffic Control Specialists. Application of chronobiological principles to this particular work schedule revealed properties that could result in opposing positions supporting or discouraging the use of the schedule. Both positions have various implications for the health and job satisfaction of the work force, as well as maintenance of safety in the air traffic system. Even though the schedule has, over the past two to three decades, been successfully used in ATC facilities, reports, such as those from the ASRS, can be found to implicate the schedule as a source of fatigue and sleepiness. Because air traffic control is a safety-related occupation, it was important to investigate the extent to which the 2-2-1 schedule could result in possible adverse effects, such as sleep disruption.

The results from the sleep pattern data analyses supported the hypothesis that the 2-2-1 significantly disrupted the sleep/wake cycle. The disruptions were primarily in the form of phase-shifting. The 2-2-1 schedule, in the present study, resulted in one phase delay of two hours, followed by two phase advances of 2- and 2.5-hours each in Asleep times (not including the shortened sleep obtained prior to the night shift). Similar patterns were found in Awake times. Thus, the schedule created a situation analogous to one east-west, and two sequential west-east flights. The phase advances occurred in this study on Tuesday and Wednesday nights (before each of the day shifts). Although the advances in Asleep and Awake times were statistically significant for the second quick-turn-around (from the day to the night shift), it was not clear how disruptive this was to the subjects.

On the weekends, subjects awoke significantly later, and therefore, obtained more sleep. The Sunday night sleep prior to starting the 2-2-1 was similar to the other weekend nights for Asleep and Awake times. The Asleep and Awake times on the weekend after the 2-2-1 were very similar to the weekend after a week of day shifts, suggesting that weekend sleep patterns were not affected by the phase shifts during the 2-2-1. It should be noted that, although this protocol scheduled days off from work to coincide with "normal" weekends, for a proportion of the ATCS work force, the days off would not be Saturday and Sunday. Finally, a significant age difference was found in Asleep times, indicating that the Older group, on the average, fell asleep approximately one hour before the Younger group over the course of the study.

The hypothesis that there would be significant decreases in the mean sleep durations (MSD) on the two quick-turn-arounds was only partially supported by the data. The MSD on the first quick-turn-around from the afternoon to the morning shift was shortened, but failed to attain statistical significance in the present study. The sleep duration on the rapid transition from the Day to the Night shift, however, was significantly shortened to 3.7 hours. Thus, the 2-2-1 only significantly decreased MSD on the afternoon prior to the Night shift, instead of the dual disruption that was possible, due to the two quick-turn-arounds.

The Sunday night sleep, just prior to the first 2-2-1 afternoon shift, was significantly longer in duration than the other days of the 2-2-1 work week. In combination with the Asleep and Awake time data, this would suggest that Sunday was treated, and could be perceived by employees, as a third weekend night.

Cumulative partial sleep loss was assessed by comparing the MSDs during the first day shift week with the 2-2-1 week on three measures: 1) the five days prior to each work day, 2) the total seven days in the week, which included the weekend after the shift, and 3) the weekend nights. While sleep debt accumulated over the 5 workdays, the subjects made up the deficit by sleeping during the day on Friday after the Night shift. Based upon the fact that the only significantly shortened sleep duration was prior to the Night shift, the 2-2-1 schedule could not be characterized as resulting in cumulative partial sleep loss in the present study.

Sleep quality ratings generally deteriorated over the course of the 2-2-1 week. Sleep was rated on the following four dimensions: difficulty falling asleep, depth of sleep, difficulty arising, and how rested the subjects felt. Scores from these four dimensions were combined into an overall sleep rating. Weekend sleep periods received the highest quality ratings. The Control Day shifts were not significantly different than weekends. After the first afternoon shift (A1) of the 2-2-1, which ended after midnight, subjects reported having more difficulty arising and feeling less rested (when compared to a weekend sleep). On the first quick-turn-around from afternoon shifts to day shifts, subjects reported feeling significantly less rested, as compared to weekend sleep. Even though subjects had nearly 14 hours off between Day shifts, the sleep pattern was phase-advanced between the first day and the second day for the second time by 2.5 hours, and subjects reported difficulty falling asleep.

As anticipated, combined sleep ratings indicated that subjects found the afternoon sleep during the transition to the Night shift to be the worst. This was related, in this group of subjects, to perceived depth of sleep when compared to sleep on a control day shift (CD1). Compared to weekend sleep quality ratings, however, the afternoon sleep of the second quick-turn-around was rated significantly lower on all four quality rating measures.

Findings from the present study paralleled those from previous studies. Sleep duration over the course of the 2-2-1 from this laboratory-based study demonstrated a similar pattern to sleep durations in CAMI studies from ATC field facilities (Saldivar et al., 1977; Melton, 1985). In the previous CAMI studies, however, sleep duration was significantly reduced for the sleep associated with Day shifts, which included the first quick-turn-around. Similar findings were recently reported from ATC field facility studies by Schroeder, Rosa, and Witt (1995) in which sleep duration declined throughout the 2-2-1 week. This was probably associated with ATC field facility Day shift start times before the 0800 start time on the first 2-2-1 day shift in this study. Early morning shift start times have been demonstrated to result in shortened sleep durations (Folkard, 1989). As with the Saldivar study (1977), the data in the present study on sleep duration suggested that any sleep debt accumulated during the 2-2-1 was recovered by the end of the weekend following the 2-2-1.

The most important finding from the present study was the demonstration of the impact of the 2-2-1 on the subjects' sleep/wake cycles. None of the previous studies had addressed the phase-shifting issues associated with the 2-2-1 schedule. Taub and Berger (1973, 1976) conducted a series of phase shift studies, in which they concluded that maintaining stable sleep schedules was of equal or greater importance than sleep duration to maintenance of performance. Phase shifts from these studies ranged from 2 to 4 hours in

both phase-advancing and phase-delaying directions. All phase-shifted conditions resulted in speed and accuracy decrements on a vigilance task, compared to performance after sleep periods normal for each individual.

Even though the 2-2-1 was found to substantially disrupt sleep patterns, performance decrements were apparent only on the night shift. (Performance data will be presented in the next report in this technical report series.) The hypothesized sleep loss and performance decrements following the first quick-turnaround were not supported in the present study. The sleep literature was examined for an explanation for this finding. Naitoh (1992) proposed the notion of "sleep quantum", or the amount of sleep needed by an individual for efficiently performing a day's work. In reviewing the partial-sleep-deprivation literature, Naitoh cited a current proposal that between from 4.5 to 5.5 hours of continuous sleep (the sleep quantum) should be taken, and that to prevent decrements in vigilance performance, a minimum of 4 hours of sleep is necessary. Examination of the sleep durations in the present study revealed that the sleep period just prior to the first turn-around was 5.7 hours, exceeding the 4-hour threshold. Sleep duration on the second quick-turn-around to the night shift (3.7 hours), however, fell below the 4-hour minimum.

Because this was a laboratory-based study with such a restrictive protocol, caution should be used in generalizing the results. The ARTCC field data collected recently suggested that the 2-2-1 schedule, as implemented in the field, was more stable, such that the work start times were more likely to be the same for the two afternoon shifts and for the two day shifts, respectively, as opposed to the 2 hour advances used in this study (Cruz & Della Rocco, 1995). Thus, employees would start both day shifts at 0600, rather than changing from an 0800 start time to an 0600 start time, as was done in this laboratory study. Analyses of the field study data suggested that the phase-shifting properties of the schedule were not as dramatic in employees who regularly work a 2-2-1 schedule as that observed in the present laboratory-based study, and that employees may adapt by stabilizing their sleep/wake patterns. On the other hand, consideration of individual differences might reveal greater disruptions in sleep patterns than were revealed in either study.

The present study was an improvement upon methodological problems inherent in a number of circadian performance studies. Instructions to subjects were to maintain stable sleep/wake patterns, mealtimes, and activities throughout the study. Daily logbooks, in conjunction with accelerometer data from the Vitalogs, were used to monitor compliance with the protocol during the study. Noncompliance was cause for dismissal from the study. Meals and breaks were provided at the same point in the work day, although subjects were not as well controlled outside of the laboratory work sessions. The A-B-A protocol was designed to ensure that subjects were day-oriented for one full week prior to introduction of the 2-2-1 schedule. Circadian core body temperature rhythms were measured during the study to verify the day-orientation. These data will be presented in one of the subsequent technical reports on this study. Self-reports of sleep data were validated in the present study through comparison to accelerometer data provided from the Vitalog physiological monitors.

The study was conducted using non-ATC subjects in a laboratory environment; therefore, the results may be conservative estimates of the effects of the 2-2-1. However, it was encouraging that the sleep patterns were similar to field studies with ATC personnel. Thus, the results obtained from this study should have applicability to serve as a basic foundation for developing of a research program on countermeasures and coping strategies.

The findings related to age differences were minimal in the present study. A possible explanation for this finding may be related to subject instructions to both groups that they maintain the most stable sleep patterns possible during the study. In addition, the Older group was selected to fall within the working ages of actual ATCSs. Therefore, the Older group was only 50-55 years old in this study. It is possible that age-related sleep changes were not observable in this particular group of subjects.

As a result of the findings in the present study, three areas were suggested for examination as candidates for countermeasures. These include the development of direct interventions to improve alertness on the night shift (bright light exposure and/or napping), sleep management education for employees, designed to

coincide with the basic tenants of the 2-2-1 schedule design, and finally, schedule redesign to minimize the number of quick-turn-arounds.

Sleep management is a critical concept for effective coping strategies with the 2-2-1 schedule. One of the basic tenants of the 2-2-1 (Melton & Bartanowicz, 1986) is that employees can maintain a day-orientation. The results of the present study, however, call this purported stability into question. Thus, employees should be instructed about the importance of maintaining a stable sleep/wake schedule, even on days off from work. This includes standardizing arise times, as well as times for exposure to sunlight in the mornings to maintain the timing of the biological clock (OTA, 1991).

Under the category of sleep management, it might be possible to improve the quality of sleep during the afternoon on the quick transition between the day and night shifts. The afternoon sleep quality could be enhanced by a) improving the sleep environment (ensuring complete darkness and quiet in the room), and b) initiating the sleep period earlier, thereby providing a greater opportunity for the individual to fall asleep, as well as increasing the duration of the sleep period.

The present study addressed only the acute effects of working one week of the 2-2-1 schedule. Future research should address the effects of working a quick-turn-around schedule on a chronic basis, as well as identification of individual differences in adaptation to the quick-turn-around schedules.

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